Use of pulse transit time in detection of upper airway obstruction in sleeping children

J.Y.A. Foo[1], S.J. Wilson[1], G. Williams[2], M.A. Harris[2], D.Cooper[2]

[1]School of Information Technology and Electrical Engineering, University of Queensland, Brisbane, Australia.
[2]Dept. Respiratory Medicine, Mater Children's Hospital, Brisbane, Australia.

Introduction

The effects of airway obstruction during sleep in children can range from mild irritation to documented IQ loss [2], [3], [4]. The patency of the upper airway is vital in maintaining ventilation. Obstructions during daytime can be noticed easily for all age groups as this is often led to coughing to overcome them. However, there is hardly any evidence of such obstructions during sleep times unless they are closely monitored. If this is left unnoticed for a long duration, there would be adverse physiological and cognitive effects, especially in children [3], [4]. In sever cases; death can even occur in young children [2]. Abnormal breathing during sleep or daytime in children has been neglected due to the misconceptions of parents. A conventional overnight sleep studies to determine the nominal respiratory pattern of individual is a complex and expensive procedure.

Pulse Transit Time (PTT) has shown the potential to estimate the degree of breathing efforts in individuals in response to involuntarily physiological changes in the upper airway. PTT is a non-invasive and indirect measure of blood pressure changes associated with obstructive breathing. This study was undertaken to determine the possible use of PTT as a screening clinical tool for children in respiratory measurement. PTT measurement was performed alongside conventional PSG studies in order to correlate obstructive events with possible PTT changes. The longer-term goal is to assess the utility of PTT as a means of detecting airway obstruction in a screening program. Such a measure would need to be robust and non-invasive. The technique described here potentially satisfies such requirements.

Method

A system using microcontroller (Atmel AVR AT90S8535) to continuously acquire physiological data from a single lead electrocardiograph (ECG) (S&W Medico Teknik Denmark) and a plethysmographic signal derived from a pulse oximeter (Novametrix Medical Systems Inc, Wallingford, USA) was developed. With an 8MHz crystal, this system has an accuracy of ± 1msec.

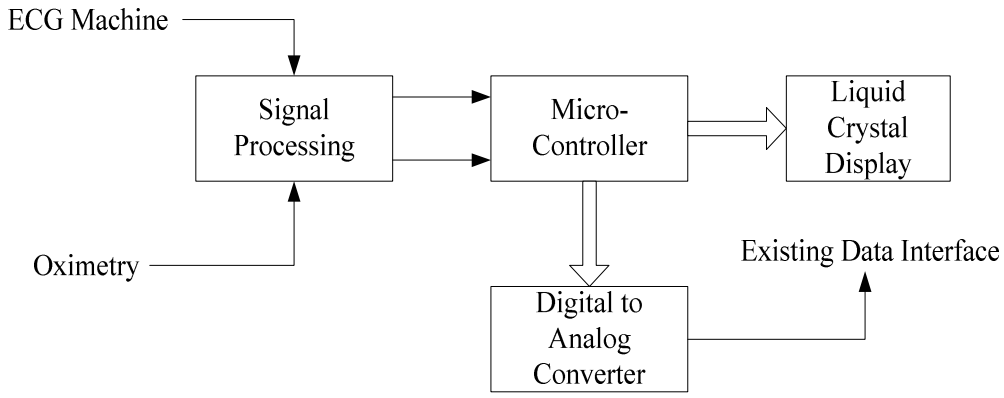

Figure 1: Block diagram of the PTT detection system

ECG signal was sampled at 1 ms interval and a slope detection algorithm used to detect the upstroke of the R wave. A differentiator in firmware then detected the peak ± 1 ms. A timer was initiated at this point. A moving threshold detector was applied to the plethysmographic signal and terminated the timer counting at 50% of the peak-to-peak amplitude. A running peak and trough detector determined the actual value to apply to the threshold detection. In this manner the effects of baseline wander and DC shifts in the applied signals were minimised. The device designed was housed in a case 140 x 70 x 25 mm and an LCD display fed back operational status to the technician. An 8-bit DAC output a voltage signal to the PSG system (NCI) so as to allow integration of the synchronised PTT with other monitored parameters over the study period.

To investigate the possible use of PTT, a screening test on the measurement of normal respiratory efforts was done on a sample of 6 child subjects; aged between 5 to 15 years. Of whom 5 have normal breathing pattern (4 male and 1 female) as well as 1 with known obstructive sleep apnoea syndrome. The subjects were asked to sit in a relaxed manner for a duration of 1 minute or more while PTT measurements were being acquired.

Results

From the obtained results, the PTT measurements for all the child subjects ranged between 220 – 290 ms. This is very similar to transit times of adults. However, these did not take into consideration the path length of the heart and the peripheral site for all subjects. The fluctuations in PTT measurements were expected as neural and physiological activities could easily cause them during awaken period. On an individual basis, PTT fluctuations are ±20 ms.

A full night sleep study was also conducted in parallel with a conventional PSG protocol. Episodes of complete airway obstruction did occur during the sleep. The corresponding effect of an obstruction event led to a significant drop in PTT measurements. In particular, the PTT measurement at that point of time was about half of its nominal value (down to about 130 ms). The body was not able to overcome the obstruction and the inspiration airflow was absent even though breathing efforts did continue. This could be observed as there were still respiration movements at the abdominal region while, movement at the rib cage ceased.

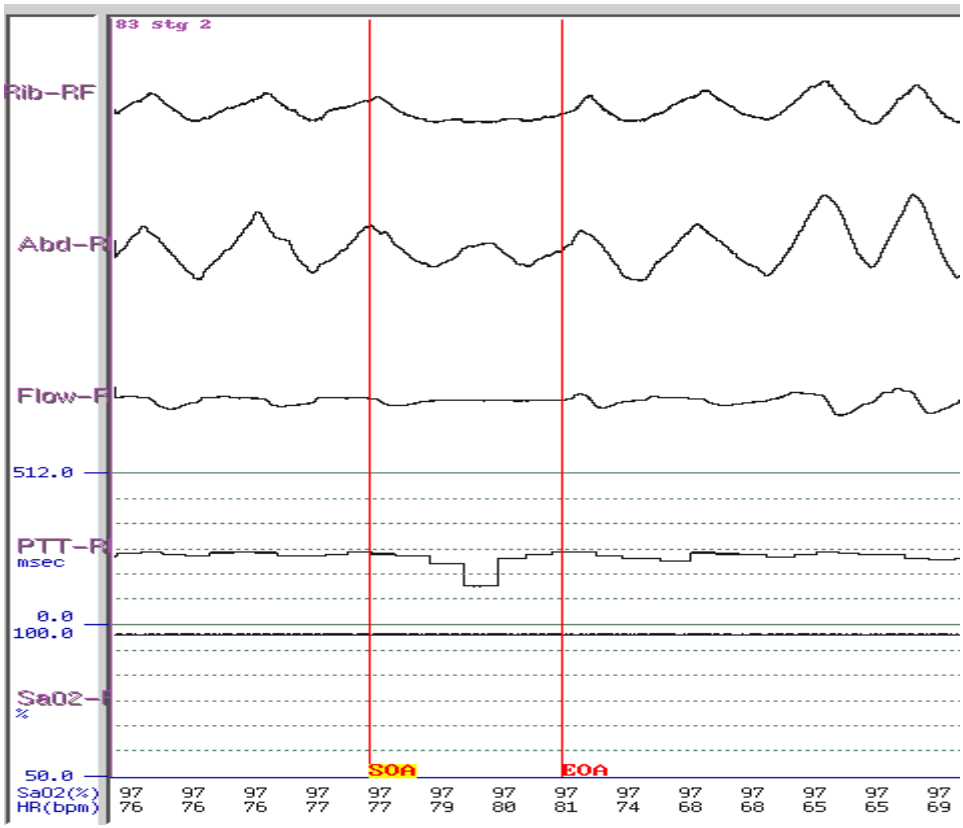

Figure 2: An obstructive event during the full night sleep studies

Discussion

The fundamental detection of apnoea and hypopnoea is based upon respiratory inductance plethysmography (RIP) and oro-nasal airflow measurement. From this data respiratory events are categorised as being obstructive or central in nature. This distinction can also be derived from an indirect approximation of blood pressure changes on each successive heartbeat. PTT is the time delay for the arterial pulse pressure wave to travel from the aortic valve of the heart to its subsequent arrival at a peripheral site, in this case a finger. The initiation of this pulse pressure wave is denoted by the R-wave on the ECG. The subsequent arrival at the finger or periphery is marked by the initial upstroke of the Photoplethysmographic signal detected by the pulse oximeter.

The principal determinants of speed by which the pulse pressure waves travel is the degree in stiffness in the arterial wall, the path length and blood constitutive properties. The arterial stiffness is largely influenced by beat-to-beat blood pressure. With the changes in the stiffness in the arterial wall, this affects the speed of wave propagation of the arterial pulse pressure wave on the arteries. A stiffer arterial wall will see a shorter PTT and vice versa. In the presence of upper airway obstruction, sympathetic outflow causes an instantaneous rise in blood pressure and thereby an increase in pulse wave velocity and decrease in PTT.

The nominal value of PTT is not subjected to the physiological variations of different subjects. It has shown promise in its abilities to detect arousals due to obstructive upper airway events. These associated arousals are accompanied by changes in heart rate and by a transient burst of sympathetic activity, which is followed by a distinctive surge in blood pressure. With its heart-beat blood pressure monitoring, scoring these cardiovascular changes in order to estimate sleep disturbances can then be possible. This arousal can be easily recognised with PTT, as it would exhibit a transient but significant dip in the nominal value. If PTT has the ability to detect arousal without the need of other complicated physiological monitoring, then it can be of great potential as part of a simplified sleep-related breathing disorder investigation.

The major limitation of PTT is the motion artefacts induced during the sleep studies. Either movement artefact affecting the plethysmographic signal at the finger or chest movement, which physically disrupts the ECG electrodes, can cause this. Motion artefact can also be confused as an obstructive event when a falsely shortened PTT is recorded. Remote sleep screening techniques require minimal instrumentation of a robust nature in order to ensure patient and technician compliance. Oronasal airflow is often difficult if not impossible to implement in the infant or child. A derived measure such as PTT could have a role in detecting obstructive where RIP and airflow monitoring would have been required otherwise. The small physical size of our device and ease of use could lead to implementation in a screening system in the longer term.

Conclusions

It has been found that PTT is able to correlate with the changes in respiratory efforts in the case studied here. Although PTT cannot qualify the degree of obstruction, it shows the ability to detect such events. Identifying obstructive events is one of the key aims of studies in sleep disordered breathing. In addition, the measurement of PTT requires single lead ECG equipment and a pulse oximeter. Since both of these devices are already used in conventional Polysomnography, it is relatively simple to monitor PTT in existing systems. [1]. PTT is a non-invasive, well tolerated and easy to measure method in these studies.

PTT measurements must be done in that breaths are averaged over a significant period of time rather than on per breath basis. Monitoring PTT can therefore be not only a useful clinical application in obstructive respiratory sleep studies, but also possibly in other respiratory studies. Normal respiratory is important for children as their physiological and cognitive developments can be greatly affected by obstructive events. In order to reduce such effects on them, early detection is then very critical. Therefore, the ease and affordability of accessing such a system can vastly help to achieve that.

Reference

[1] D.J. Pitson and J.R. Stradling, "Value of Beat-to-Beat Blood Pressure Changes, Detected by Pulse Transit Time, in the Management of the Obstructive Sleep Apnoea/Hypopnoea Syndrome", *The European Respiratory Journal,* 1998, Vol. 12, pp. 685-692.

[2] F. McNamara, and C.E. Sullivan, "Evolution of Sleep-disordered Breathing and Sleep in Infants", *Journal of Paediatrics and Child Health*, Feb. 1998, Vol. 34, No. 1, pp. 37-43.

[3] G.M. Loughlin, "Obstructive Sleep Apnea in Children", *Advances in Pediatrics*, 1992, Vol. 39, pp. 307-336.

[4] P. Varady, and S. Bongar, "Detection of Airway Obstruction and Sleep Apnea by Analyzing the Phase Relation of Respiration Movement Signals", *Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference. Rediscovering Measurement in the Age of Informatics*, May 2001, Vol. 1, pp. 185-190.